Forest response to rising CO_2 drives zonally asymmetric rainfall change over tropical continents

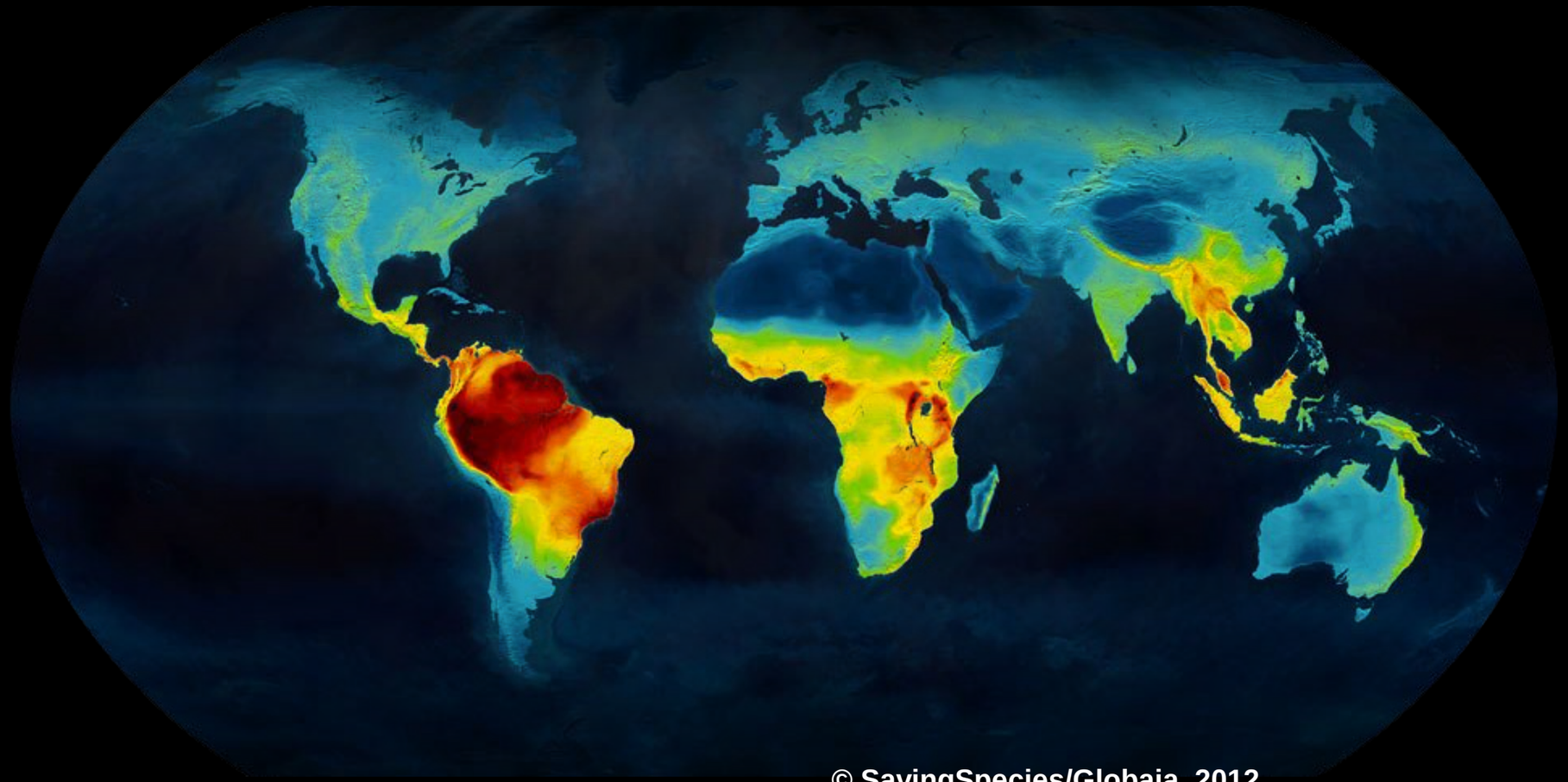
Gabriel Kooperman

Yang Chen, Forrest Hoffman, Charles Koven, Keith Lindsay, Michael Pritchard, Abigail Swann, and James Randerson

March 2, 2017

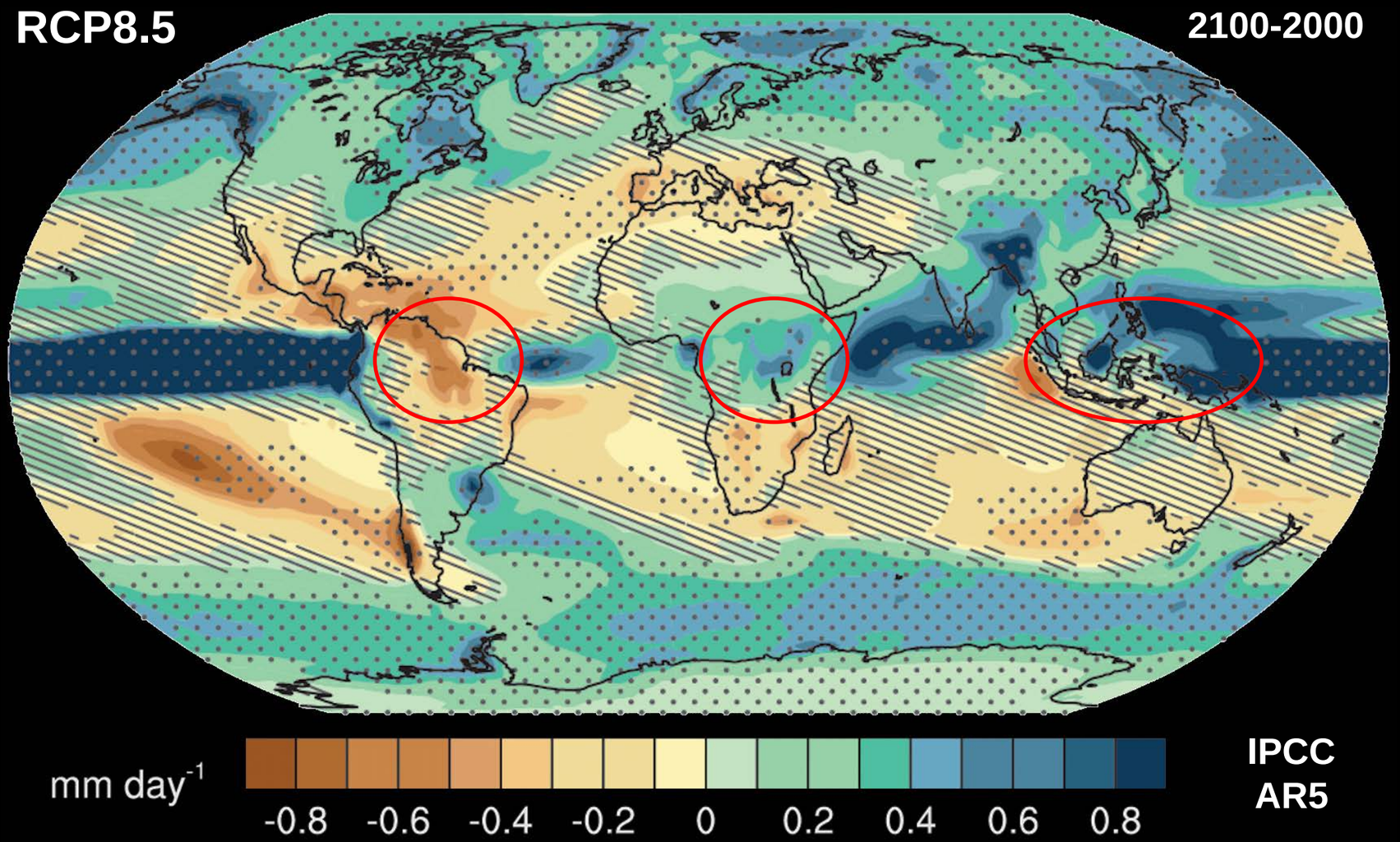
Tropical forests play a critical role in global carbon cycling and biodiversity, but are vulnerable to future precipitation changes

Global Density of Vertebrate Species



Unfortunately, future projections of annual mean precipitation changes over tropical forests have seemed uncertain

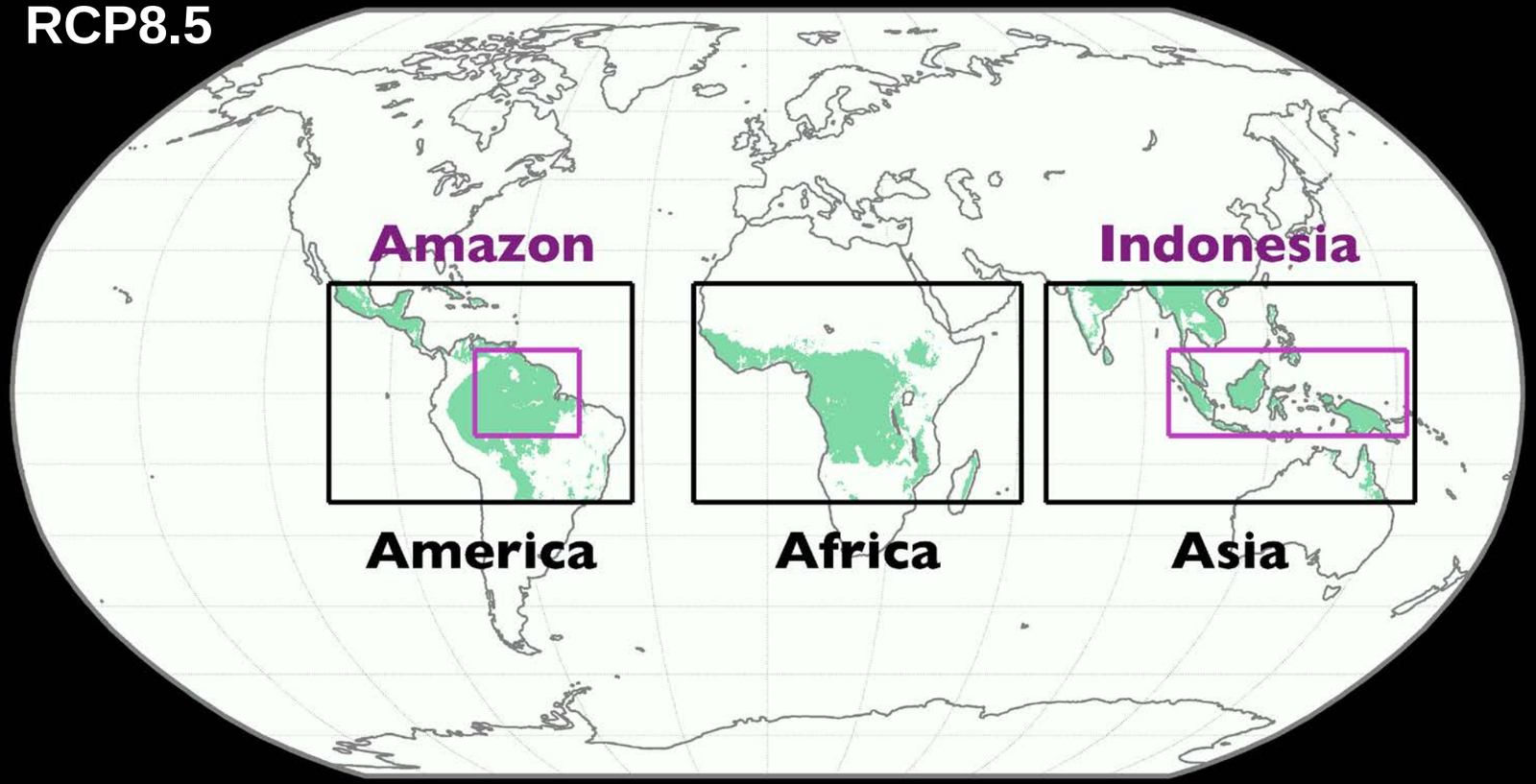
Annual Mean Precipitation Change



Despite this uncertainty, all modern climate models project a growing zonally asymmetric rainfall pattern across the tropics

Annual Mean Precipitation Change

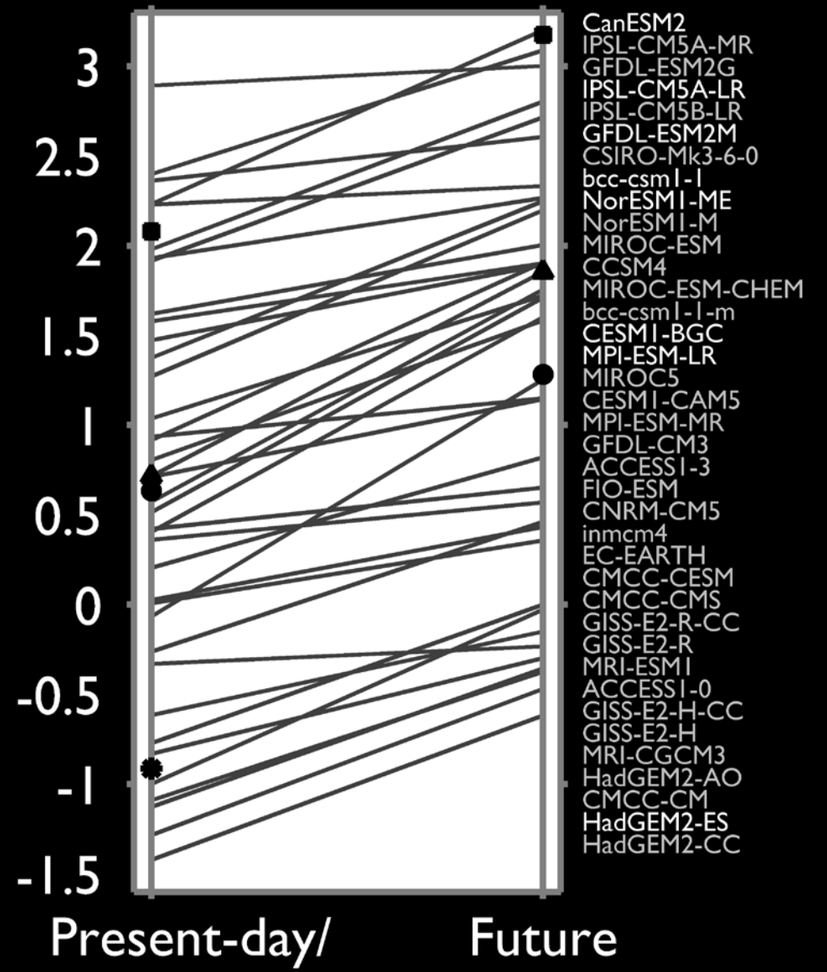
RCP8.5



Tropical Precipitation Asymmetry Index

$$I_{TPA} = (P_{Asia} + P_{Africa})/2 - P_{America}$$

Precipitation Asymmetry



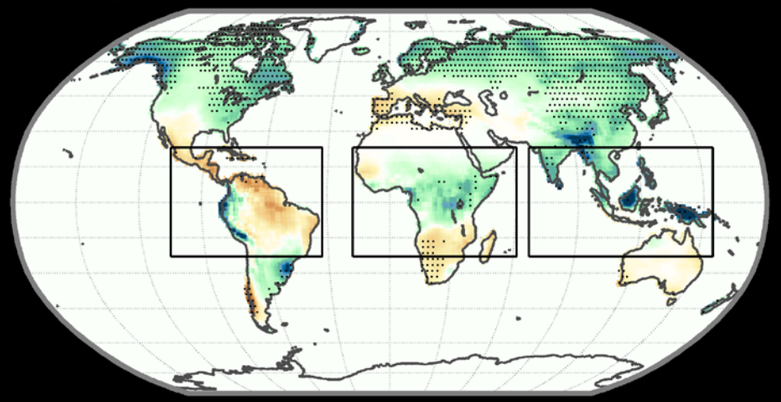
Kooperman *et al.*, in review (2017)

Asymmetric precipitation pattern is driven by both radiative greenhouse and plant physiological responses to increasing CO_2

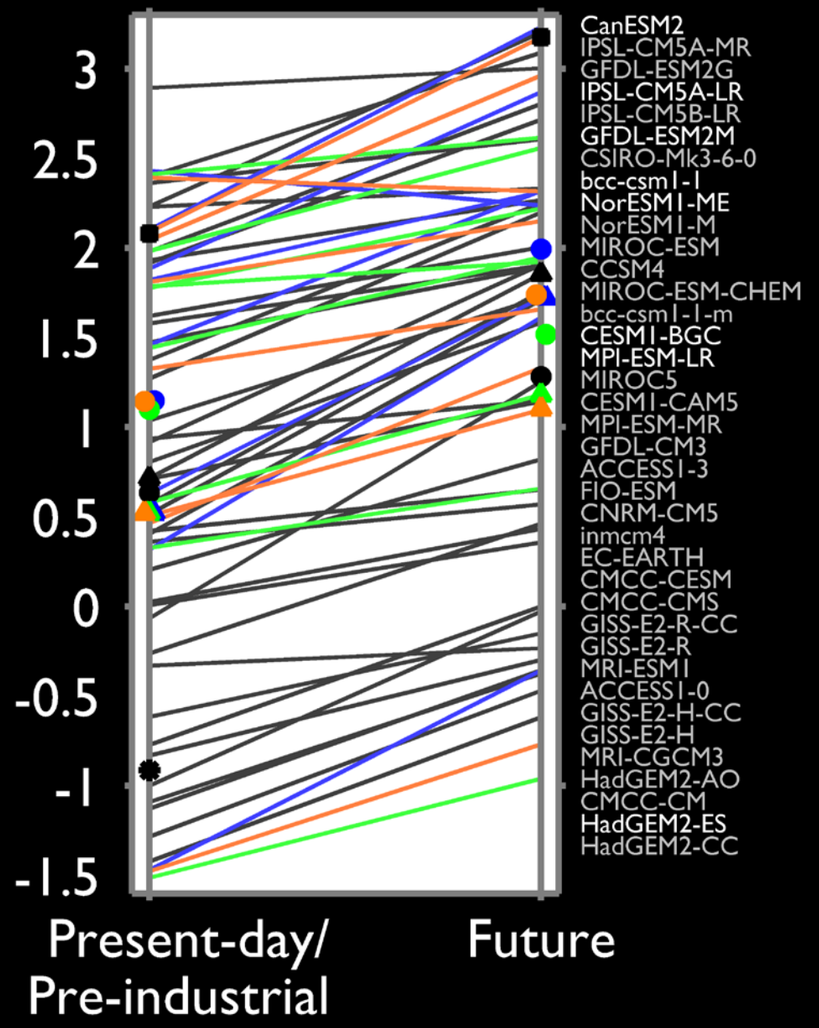
Annual Mean Precipitation Change

RCP8.5

CO_2-Only: Radiation + Physiology



Precipitation Asymmetry

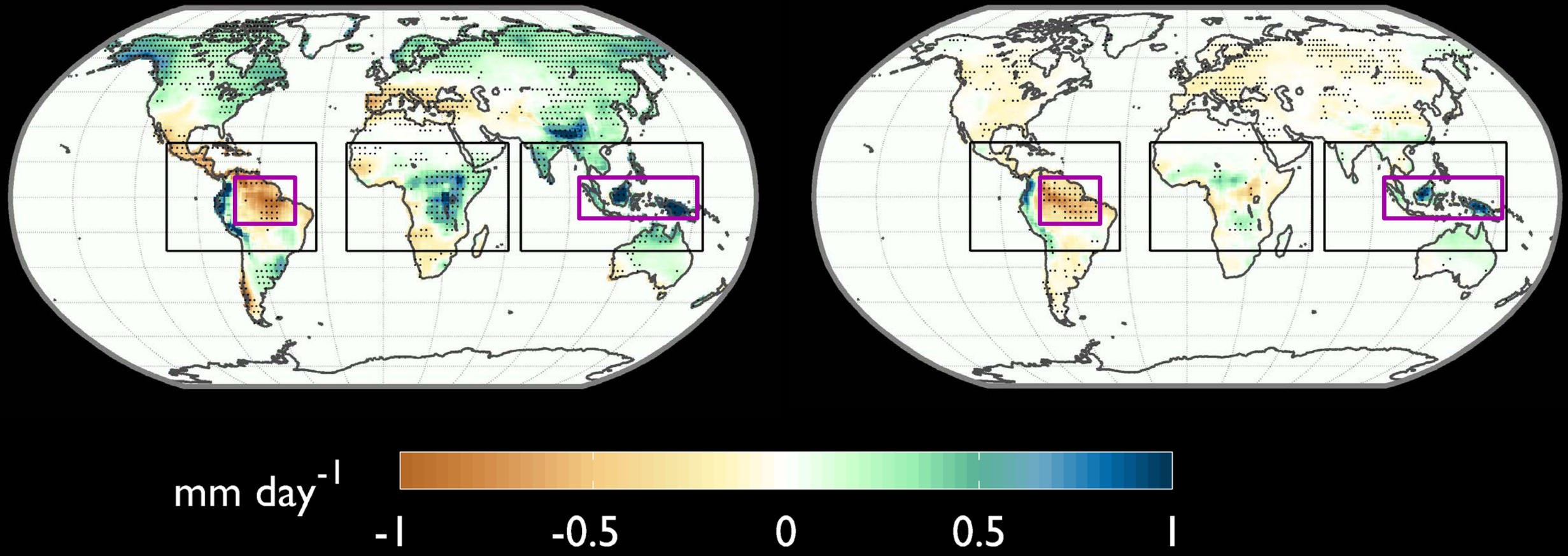


Physiological responses alone are a dominant component of the overall precipitation change over dense tropical forests

Annual Mean Precipitation Change

CO_2-Only: Radiation + Physiology

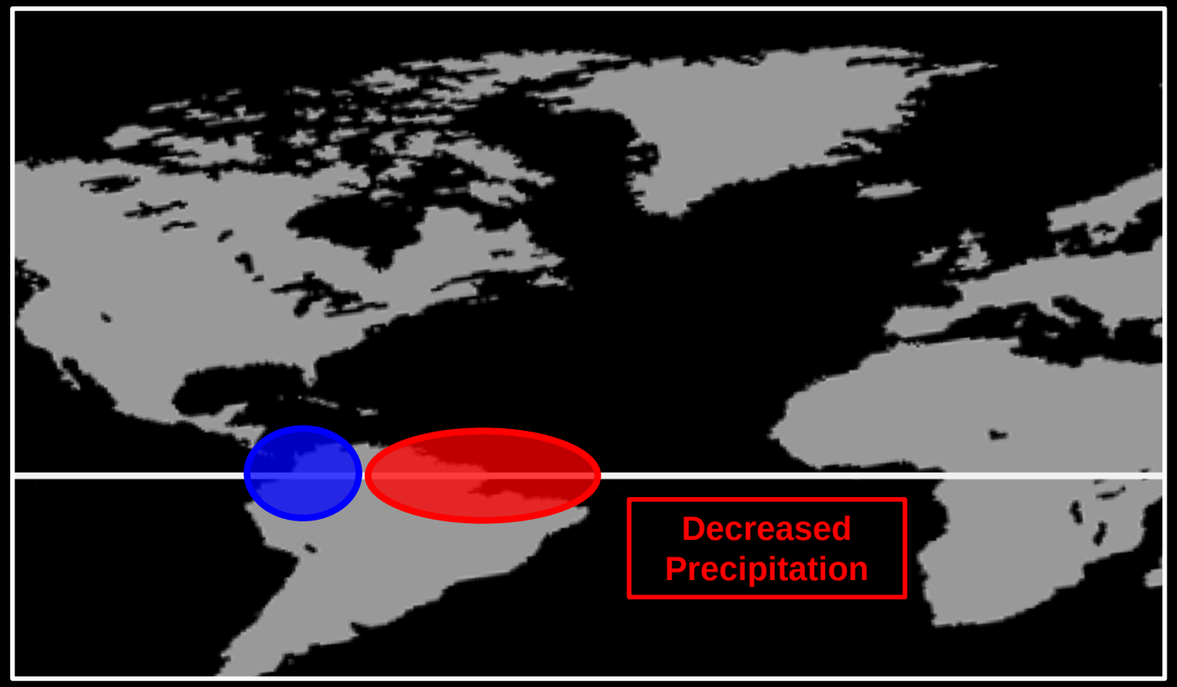
Physiology



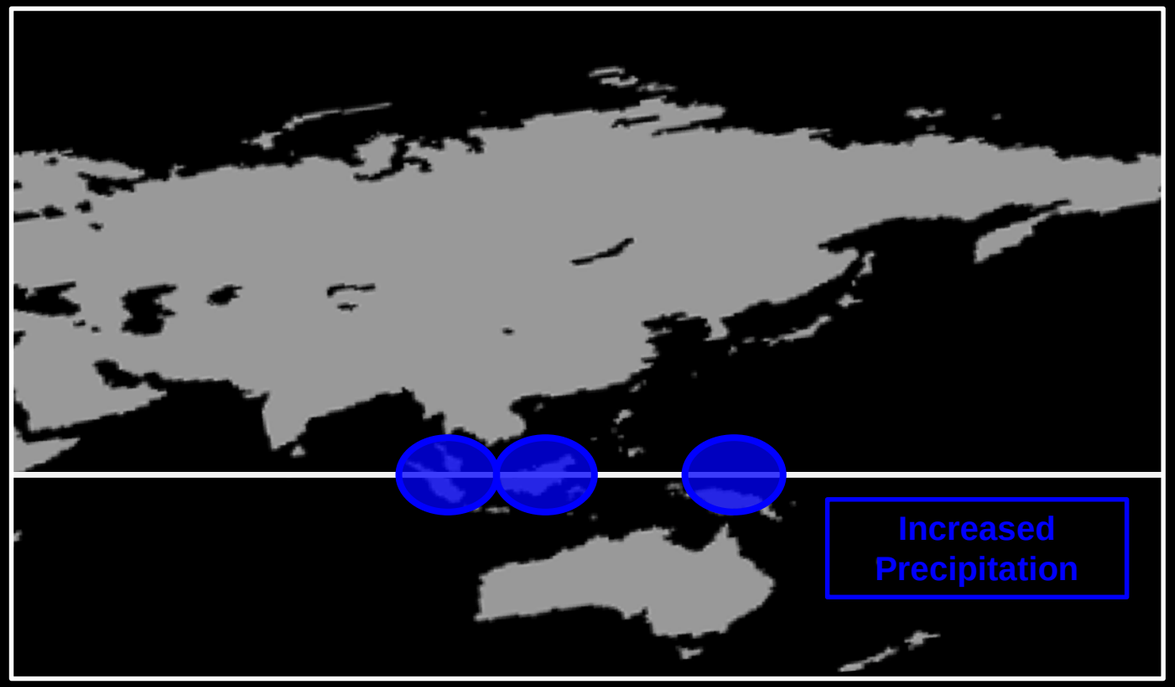
What drives this asymmetric pattern of change?

How do physiological responses contribute to these changes?

Amazon



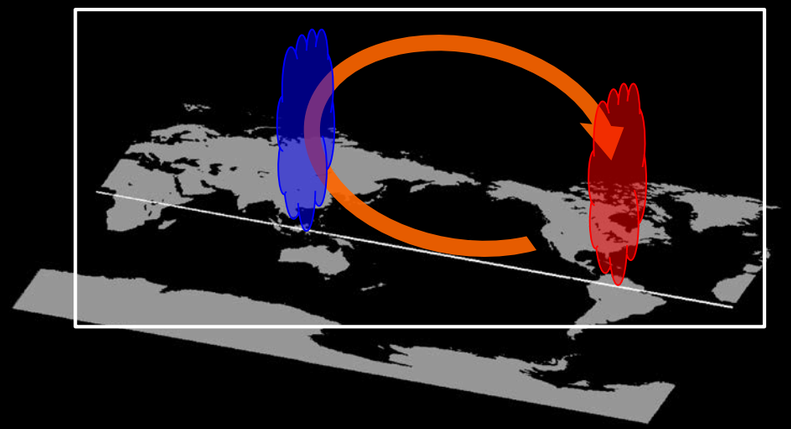
Indonesia



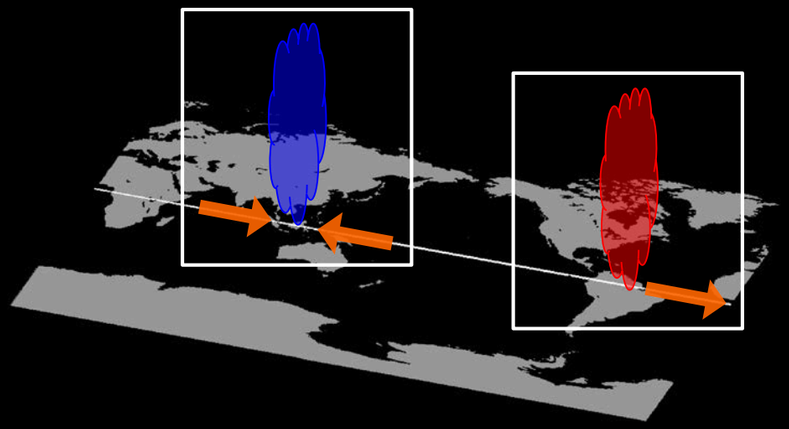
Precipitation ↑
Precipitation ↓

A new experiment with CESM tests if the pattern is driven by tropics-wide (e.g. Walker Circulation) or regional mechanism

Tropics Wide Mechanism



Regional Mechanisms



Community Earth System Model

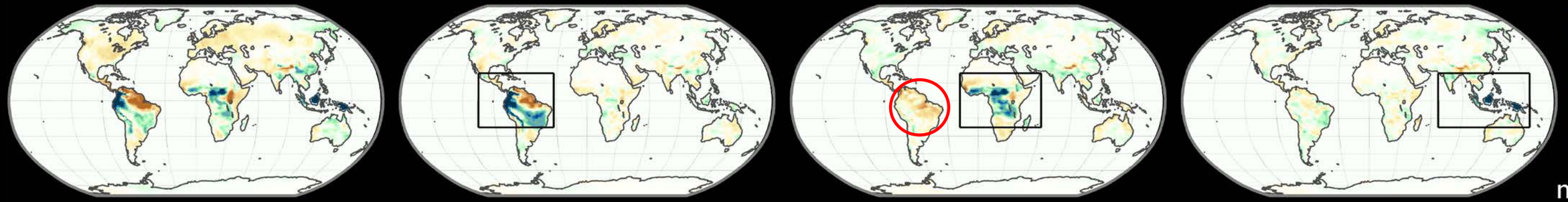
Annual Mean Precipitation Change

Global

America

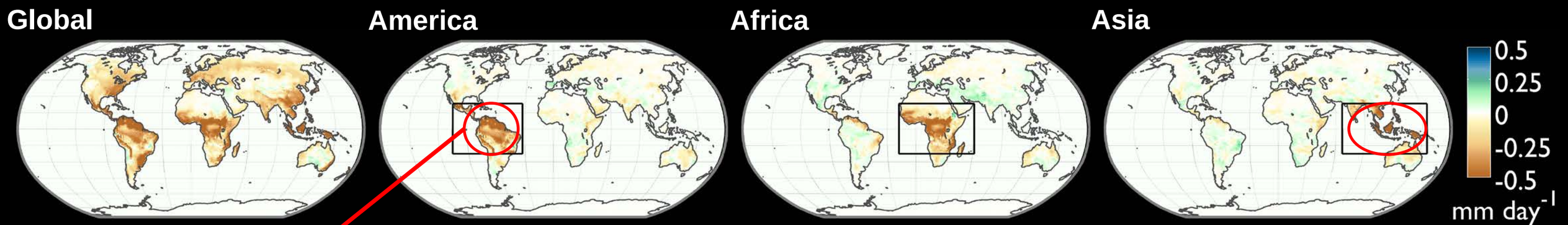
Africa

Asia



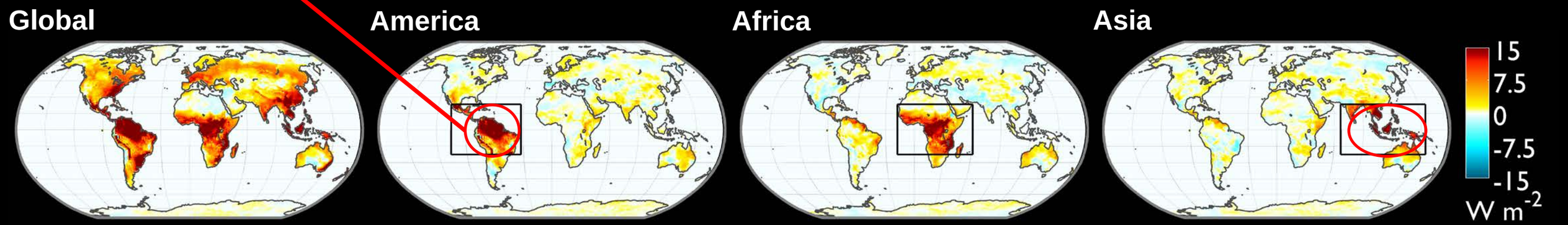
Rising CO_2 reduces stomatal conductance and transpiration, modifying surface heat fluxes and near-surface air conditions

Annual Mean Evapotranspiration Change



Suppressed Convection

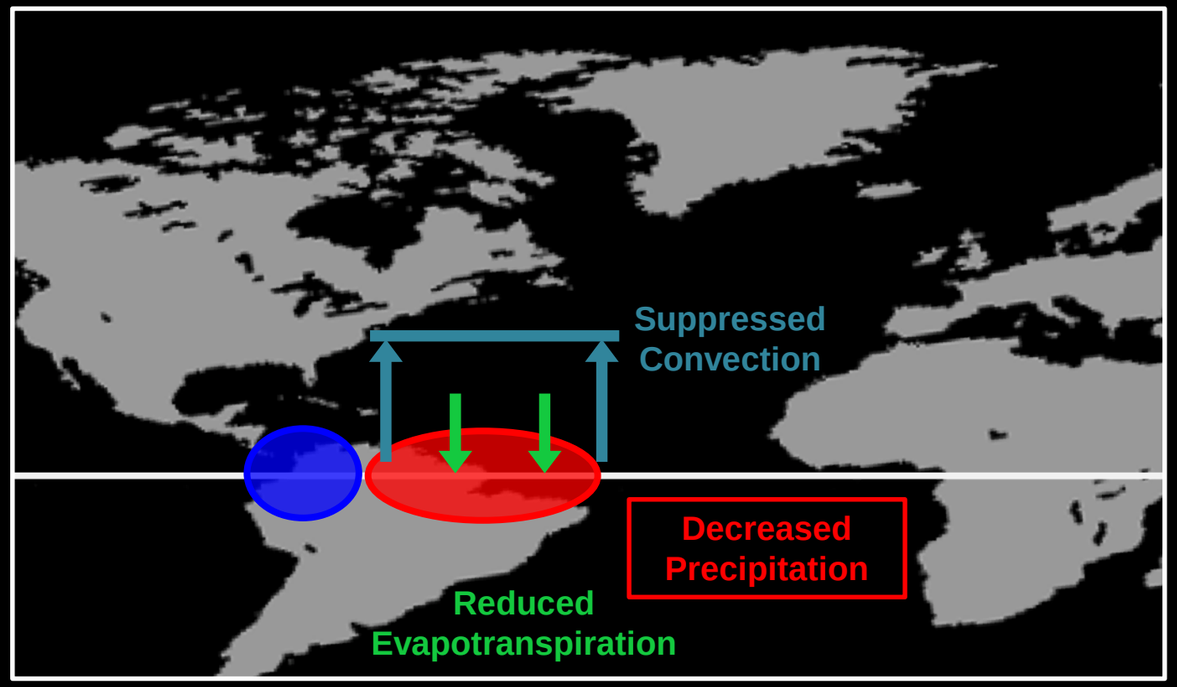
Annual Mean Sensible Heat Flux Change



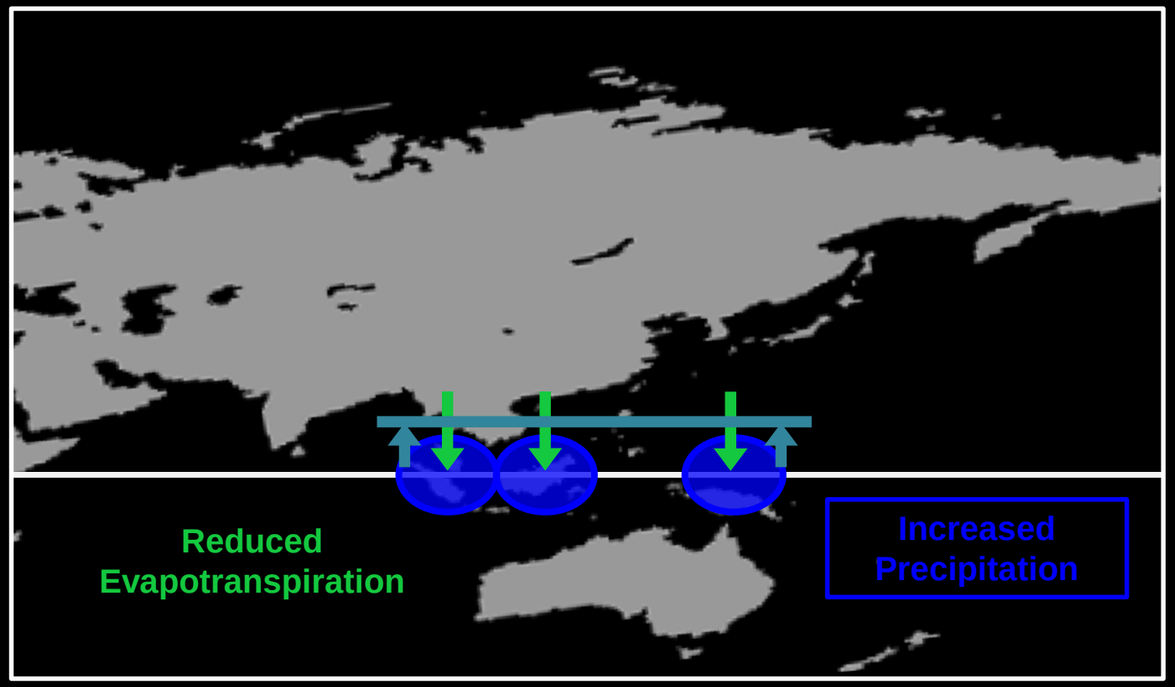
What drives this asymmetric pattern of change?

How do physiological responses contribute to these changes?

Amazon



Indonesia



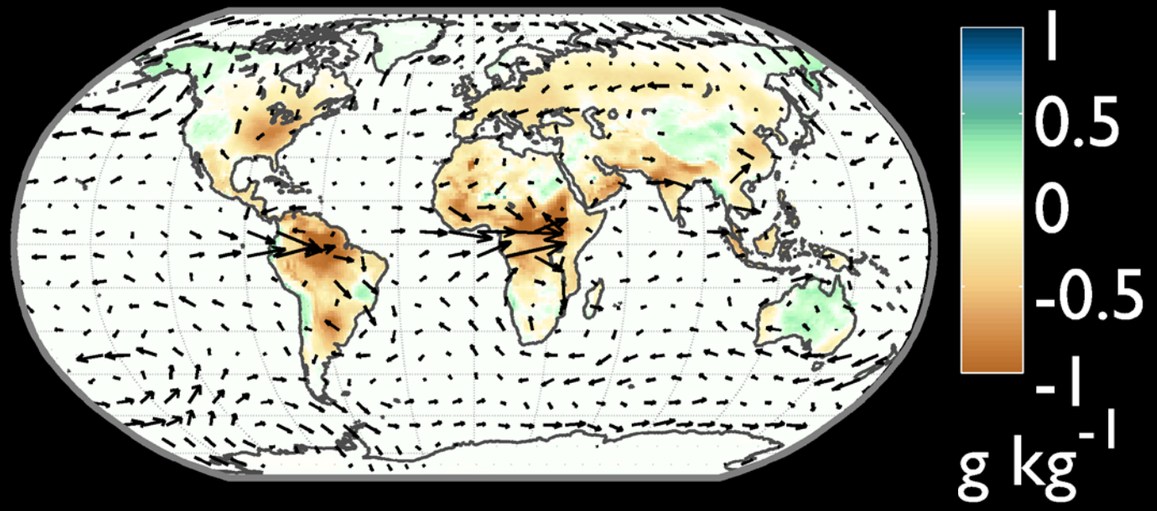
Precipitation ↑ Evapotranspiration ↓
Precipitation ↓ Condensation Level ↑

Surface flux changes drive convectively-coupled and island-like circulations over the Amazon and Indonesia, respectively

Annual Mean Specific Humidity Change

Near Surface

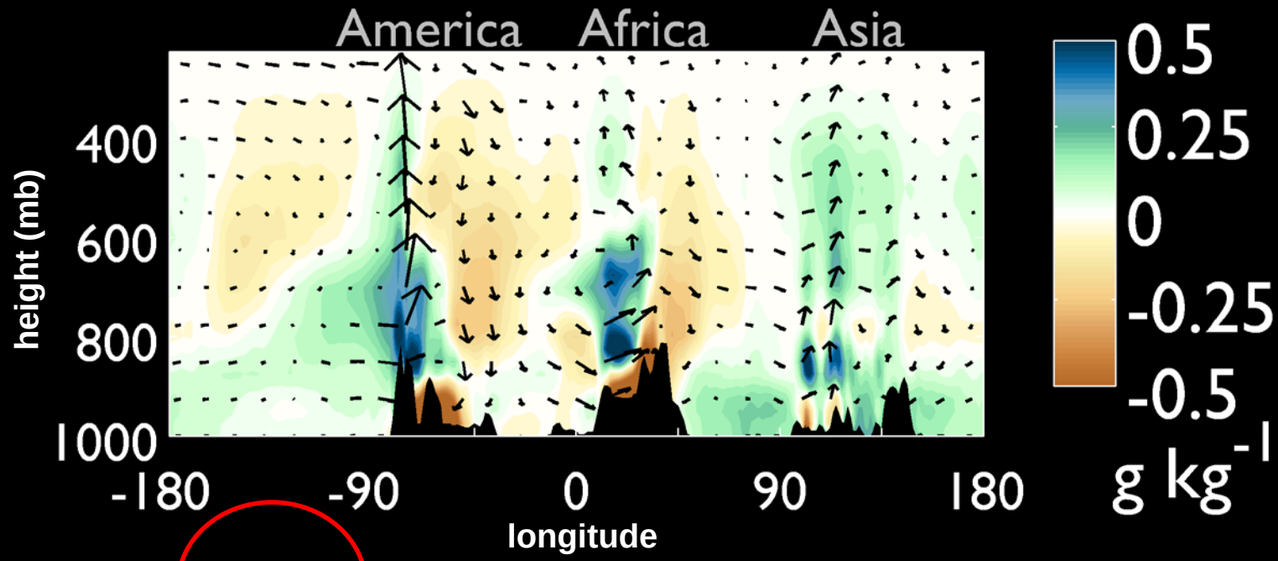
Global



Low-level Wind (850 mb)

Tropical (5˚S - 5˚N)

Global

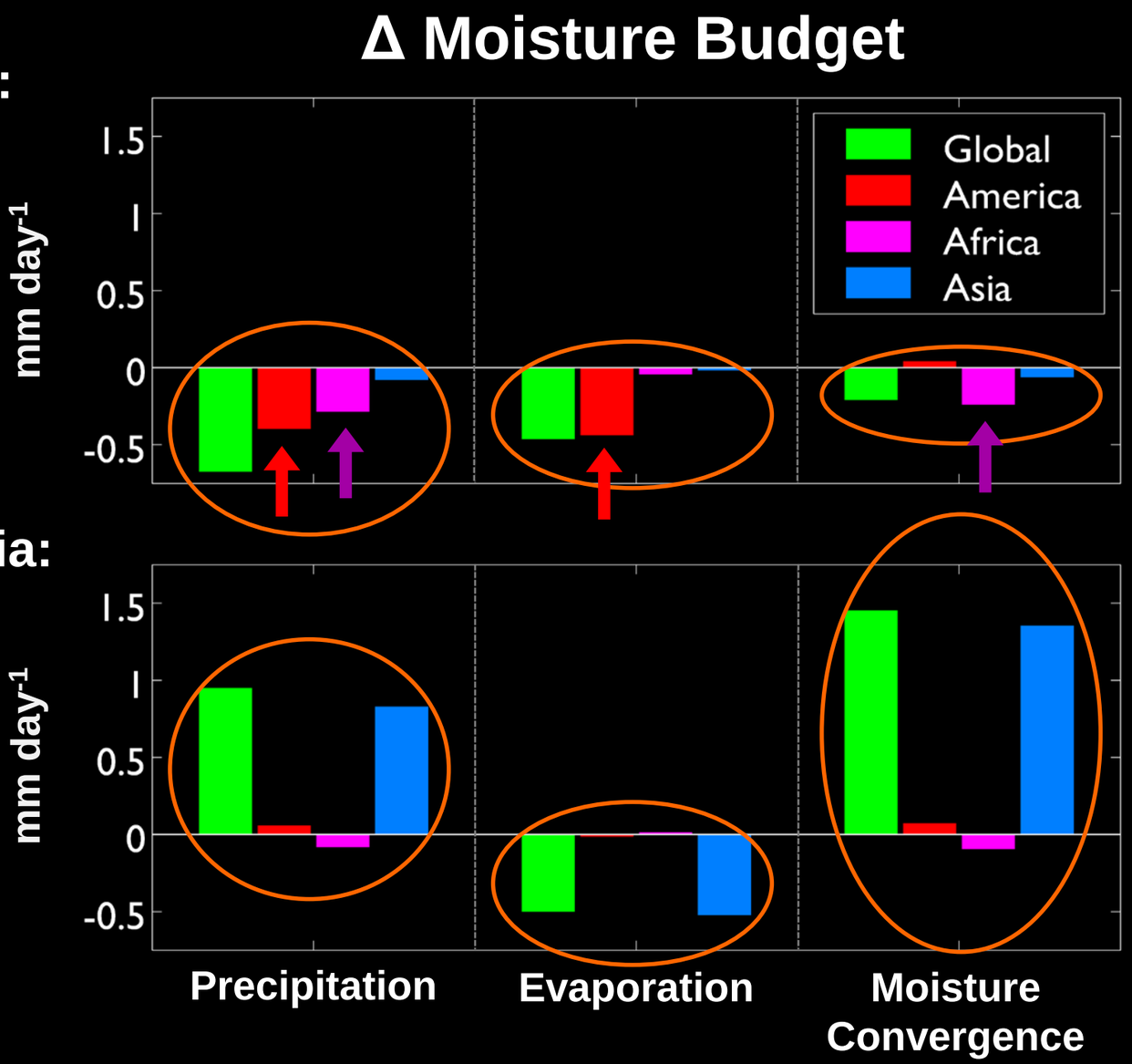


Zonal and Vertical Wind

Locally and non-locally driven moisture convergences changes lead to less rainfall over the Amazon and more over Indonesia

Amazon:

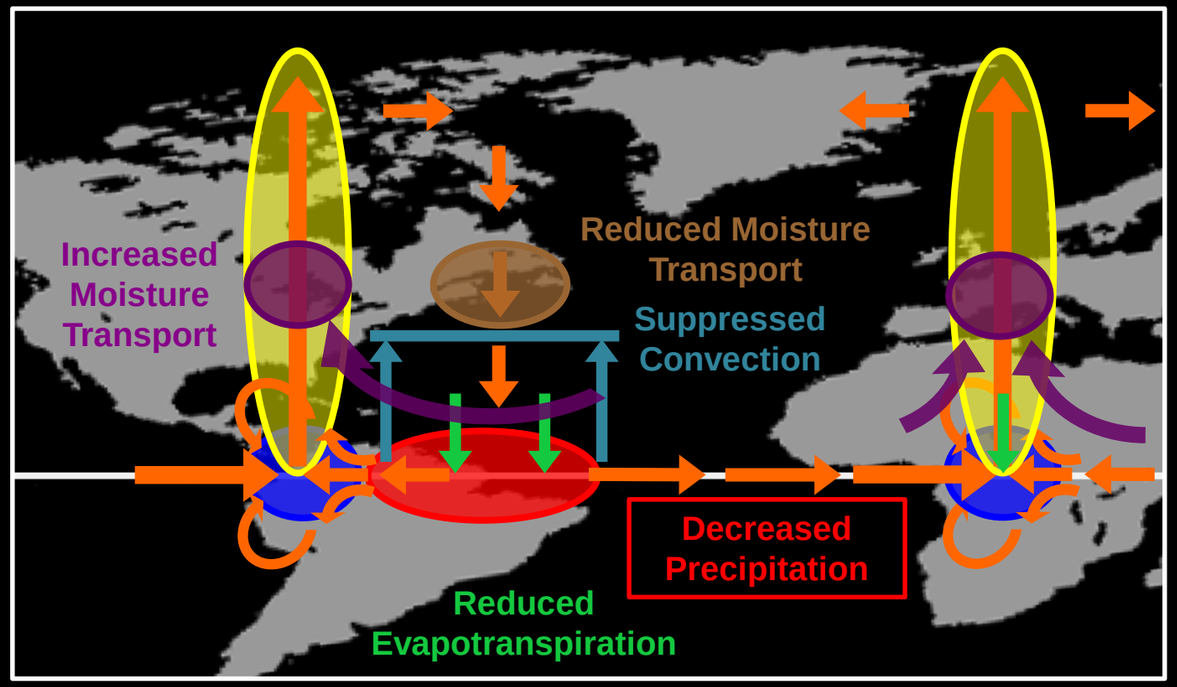
Indonesia:



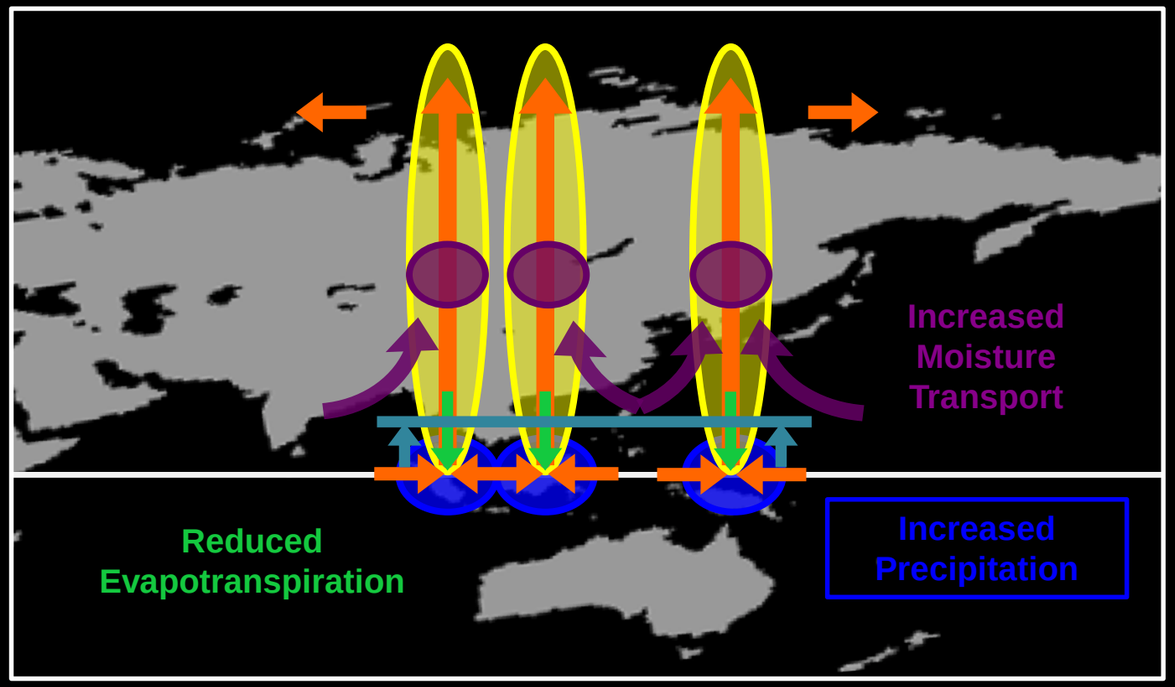
What drives this asymmetric pattern of change?

How do physiological responses contribute to these changes?

Amazon



Indonesia



Precipitation ↑ Evapotranspiration ↓ Convective Heating ↑ Moisture Convergence ↑

Precipitation ↓ Condensation Level ↑ Circulation Anomaly ← Moisture Convergence ↓

Conclusions: Local and non-local responses to rising CO_2 may make the Amazon may be more vulnerable than other forests

- Nearly all CMIP5 models predict a strengthening zonal precipitation asymmetry across tropical forests.